Chapter 6- Two-phase Gas-oil Separation

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a) Gas velocity

$$U_g = \frac{Q_g}{0.75\left(\frac{\pi}{4}D^2\right)} = 80\frac{Q_g}{D^2}\left(\frac{TZ}{P}\right) \text{ ft/s} \tag{1}$$

- Time for a gas droplet to travel across effective length

$$t_g = \frac{L_g}{u_g} \tag{2}$$

- Time for a liquid droplet with dm to fall from the top of the separator to liquid surface:

$$t_s = \left(\frac{0.71D}{12}\right)\left(0.01186\left[\left(\frac{\rho_0 - \rho_g}{\rho_g}\right)\frac{dm}{C_d}\right]^{\frac{1}{2}}\right)^{-1} \tag{3}$$

Equating *(*2) and (3), and substituting (1) for Ug

$$DL = 198\frac{Q_g TZ}{P}\left[\left(\frac{\rho_g}{\rho_o - \rho_g}\right)\frac{Cd}{dm}\right]^{\frac{1}{2}} \tag{4}$$

Liquid capacity constraint

$$V_o = (0.25)\left(\frac{\pi}{4}\right)\left(\frac{D}{12}\right)^2 L$$

$$Q_o = 257\frac{V_o}{t} \qquad (1 \text{ ft}^3 / \text{min} = 257 bbl / day)$$

Combining the two equations;

$$D^2 L = 2.856 Q_o t$$

b) 25% gas

$$U_g = \frac{Q_g}{0.25\left(\frac{\pi}{4}D^2\right)} = 240\frac{Q_g}{D^2}\left(\frac{TZ}{P}\right)$$

(1)

$$t_g = \frac{L_g}{u_g} \qquad (2)$$

$$t_s = \left(\frac{0.29D}{12}\right)\left(0.01186\left[\left(\frac{\rho_0 - \rho_g}{\rho_g}\right)\frac{dm}{C_d}\right]^{\frac{1}{2}}\right)^{-1}$$

(3)

Equating *(*2) and (3), and substituting (1) for Ug

$$DL = 1455\frac{Q_g TZ}{P}\left[\left(\frac{\rho_g}{\rho_o - \rho_g}\right)\frac{Cd}{dm}\right]^{\frac{1}{2}} \qquad (5)$$

Liquid capacity constraint

$$V_o = (0.75)\left(\frac{\pi}{4}\right)\left(\frac{D}{12}\right)^2 L$$

$$Q_o = 257\frac{V_o}{t} \qquad (1\ \text{ft}^3/\text{min} = 257 bbl/day)$$

Combining the two equations;

$$D^2 L = 0.951 Q_o t$$

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$$\gamma_g = 0.6 \longrightarrow P_{pc} = 679\,psi \ , \ \mathrm{T}_{pc} = 353^o R$$

$$P_{pr} = \frac{500}{679} = 0.74 \quad , \quad \mathrm{T}_{pr} = \frac{80+460}{353} = 1.53$$

$$\longrightarrow z = 0.93 \qquad \longrightarrow \mu_g = 0.013 \text{ cl}$$

$$\rho_g = 2.7\gamma_g \frac{P}{TZ} = 2.7(0.6)\left(\frac{500}{(540)(0.93)}\right) = 1.6 \text{ lb/ft}^3$$

$$35^o\,API = \frac{141.5}{\gamma_o} - 131.5 \quad \longrightarrow \gamma_o = 0.85$$

$$\rho_o = 0.85 \times 62.4^o = 53.03 \text{ lb/ft}^3$$

Assuming Cd=0.34

$$4 = 0.01186\left[\left(\frac{\rho_o - \rho_g}{\rho_g}\right)\left(\frac{dm}{Cd}\right)\right]^{\frac{1}{2}}$$

$$= 0.01186\left[\left(\frac{53.05-1.6}{\rho_g}\right)\left(\frac{dm}{Cd}\right)\right]^{\frac{1}{2}} = 1.15 \text{ ft/s}$$

$$R_c = 0.0049\frac{\rho_g d_m 4}{\mu_g} = 0.0049\frac{(1.6)(100)(1.15)}{(0.013)} = 69.8$$

$$C_d = 0.34 + \frac{3}{R_c^{0.5}} + \frac{24}{R_c} = 0.34 + \frac{3}{69.8^{0.5}} + \frac{24}{69.8} = 1.04$$

Iterations:

$$\rightarrow \text{ u}'\text{=0.66 , R}_c{}' = 40.05 \text{ , C}_d = 1.41$$

$$\rightarrow \text{ u}'\text{=0.56 , R}_c{}' = 34 \text{ , C}_d = 1.56$$

$$\rightarrow \text{ u}'\text{=0.66 , R}_c{}' = 32.16 \text{ , C}_d = 1.61$$

$$Q_g = GOR \times Q_o = 1200 \times 8000 = 9.6 \text{ mmSCF}$$

a) Horizontal separator

Gas Capacity Constraint

$$DL_g = 422\left(\frac{TZQ_g}{P}\right)\left[\left(\frac{\rho_g - C_d}{\left(\rho_o - \rho_g\right)d_m}\right)\right]^{\frac{1}{2}}$$

$$= 422\left(\frac{(540)(0.93)(9.6)}{500}\right)\left[\frac{(1.6)(1.61)}{(53.03-1.6)(100)}\right]^{\frac{1}{2}}$$

$$= 91.06 \ \text{ in.ft}$$

Oil Capacity

$$D^2 L_o = 1.428 Q_o t = 1.42(8000)(3) = 43272 \ \text{in}^2 . ft$$

$$L_{sg} = L_g + \frac{D}{12} \quad , \quad \text{L}_{so} = \frac{4}{3} L_o$$

D	L_g	L_o	L_s	SR
60	1.51	9.52	12.69	2.54
54	1.69	11.75	15.67	3.48
48	1.9	14.88	19.83	4.96
42	2.17	19.43	25.91	7.40

The smallest diameter that satisfies the slenderness ratio criteria is 48.

D_{in}=48 in, L_s=20 ft

b) Offshore platform --- vertical separator

Gas Capacity Constraint

$$D_{\min}^2 = 5058\left(\frac{TZQ_g}{P}\right)\left[\left(\frac{\rho_g - C_d}{\left(\rho_o - \rho_g\right)d_m}\right)\right]^{\frac{1}{2}}$$

$$= 5058\left(\frac{(540)(0.93)(9.6)}{500}\right)\left[\frac{(1.6)(1.61)}{(53.03-1.6)(100)}\right]^{\frac{1}{2}}$$

$$= 1091.5$$

$$D_{\min} = 33.04 \ \text{in}$$

Gas Capacity Constraint

$$D^2H = 8.565Q_o t = 8.565(8000)(3) = 205560 \text{ in}^2.ft$$

D	H	L_s	SR
36	158.61	19.55	6.52
42	116.53	16.54	4.73
48	89.22	14.77	3.69
54	70.50	9.54	2.39

The smallest diameter satisfying the SR criteria is 42 in.

D_{in}=48 in, L_s=20 ft

c)

$$15 \text{ ft} = L_g + \frac{60}{5} \rightarrow \text{ L}_g = 10 \text{ ft}$$

$$(60)(10) = 422\left(\frac{(540)(0.93)\,\text{Q}_g}{500}\right)\left[\frac{(1.6)(1.61)}{(53.03-1.6)(100)}\right]^{\frac{1}{2}}$$

$$\rightarrow \text{ Q}_g = 62.7 \text{ mmSCFD}$$

$$15=\frac{4}{3}\text{L}_o \ \rightarrow \ \text{L}_o = 11.25 \text{ ft}$$

$$(60)^2(11.25) = 1.428\text{Q}_o(3) \ \rightarrow \ \text{Q}_o = 9454 \text{ bbl/day}$$

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Vertical separator

$$\mathrm{L}_s = \frac{H + D + 40}{12} = 16 \text{ ft} = \frac{H + 48 + 40}{12}$$
$$= 104 \text{ in}$$

$$\rho_o = 0.875(62.4) = 54.6 \text{ lb/ft}^3$$
$$\rho_g = 2.7(0.6)\frac{(585 + 14.7)}{(540)(0.89)} = 2.02 \text{ lb/ft}^3$$

Oil Capacity

$$(48)^2 = 5058\left(\frac{(540)(0.89)Q_g}{(600)}\right)\left[\left(\frac{(2.02)(0.89)}{(54.6 - 2.02)(0.89)}\right)\right]^{\frac{1}{2}}$$
$$\rightarrow \mathrm{Q}_g = 31.27 \text{ mmscFD}$$

Horizontal separator

$$L_g = 16 - \frac{48}{4} = 12 \text{ ft}$$
$$(48)(12) = 422\left(\frac{(540)(0.89)Q_g}{600}\right)\left[\frac{(2.02)(0.86)}{54.6 - 2.02)(0.89)}\right]^{\frac{1}{2}}$$
$$\rightarrow \mathrm{Q}_g = 93.7 \text{ mmscFD}$$
$$\mathrm{L}_o = \frac{3}{4}(16) = 12 \text{ ft}$$
$$(48)^2(12) = 1.428Q_o(2) \rightarrow \mathrm{Q}_o = 9680.7 \text{ bbl/d}$$

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Horizontal Scrubber

$$\gamma_o = \frac{141.5}{131.5+40} = 0.825 \quad \rightarrow \; \rho_o = 0.825(62.4) = 51.49 \text{ lb/ft}^3$$

$$\text{T}_{pc} = 353^o R \quad , \quad \text{P}_{pc} = 679\, psi \quad , \quad \text{T=80+460=540}^o R$$

$$\text{T}_{pr} = \frac{540}{353} = 1.53 \quad , \quad \text{P}_{pr} = \frac{1200}{679} = 1.77$$

$$\rightarrow z = 0.85$$

$$\rightarrow \mu_g = 0.014$$

$$\rho_g = 2.7(0.6)\frac{(1200)}{(540)(0.85)} = 4.24 \text{ lb/ft}^3$$

$$\text{assuming C}_d = 0.34$$

$$u = 0.01186\left[\left(\frac{51.49-4.24}{4.24}\right)\left(\frac{500}{0.34}\right)\right]^{\frac{1}{2}} = 1.518$$

$$R_e = 0.0049\left(\frac{(4.24)(500)(1.518)}{0.014}\right) = 1126.4$$

$$C_d = 0.34 + \frac{3}{1123.4^{\frac{1}{2}}} + \frac{24}{1126.4} = 0.45$$

u	R_e	C_d
1.32	979.4	0.46

We need to derive an expression for gas capacity constraint that allocates the majority of the separator volume to gas, while leaving a small area for liquid settling. We will allocate 90% of the separator volume for gas.

Gas velocity

$$u_g = \frac{Q_g}{0.9(\frac{\pi}{4}D^2)} = 66.67\frac{Q_g}{D^2}\left(\frac{TZ}{P}\right) \quad \text{ft/s} \qquad (1)$$

Time for a gas droplet to travel across effective length

$$t_g = \frac{L_g}{u_g} \tag{2}$$

Time for a liquid droplet to fall from the top of the scrubber to the liquid surface

$$t_s = \left(\frac{0.88D}{12}\right)\left(0.01186\left[\left(\frac{\rho_o - \rho_g}{\rho_g}\right)\frac{d_m}{C_d}\right]^{\frac{1}{2}}\right)^{-1}$$

(3)

Equating (2) and (3), and substituting with (1) for u_g

$$DL = 133.2 Q_g \frac{TZ}{P}\left[\left(\frac{\rho_g}{\rho_o - \rho_g}\right)\left(\frac{C_d}{d_m}\right)\right]^{\frac{1}{2}}$$

$$= 133.2 \frac{(80)(540)(0.85)}{(1200)} \times \left[\left(\frac{(4.24)(0.46)}{(51.49 - 4.24)(500)}\right)\right]^{\frac{1}{2}}$$

$$= 35.91 \text{ in.ft}$$

Oil capacity is negligible.

A 24 in diameter by 3 ft L_s would be sufficient.

Horizontal Scrubber

$$D_{\min}^2 = 5058 \frac{(20)(540)(0.85)}{(1200)}\left[\frac{(4.24)(0.46)}{(51.5 - 4.24)(500)}\right]^{\frac{1}{2}}$$

$$\rightarrow D_{\min} = 36.93 \text{ in} \simeq 42 \text{ in}$$

allowing 1 foot for liquide settling $\rightarrow$ H=12 in

$$L_s = \frac{12+42+40}{12} = 7.83 \text{ ft} \simeq 8 \text{ ft}$$

D=42 in , $L_s = 8$ ft

Chapter 7- Three-Phase Oil-Water-Gas Separation

<u>3</u>

$$\frac{A_w}{A} = 0.5\frac{Q_w t_w}{Q_o t_o + Q_w t_w} = 0.5\frac{3000\times 6}{8000\times 10 + 3000\times 6} = 0.092$$

from figure $\rightarrow$ $H_o/D = 0.35$

$$\gamma_o = \frac{141.5}{131.5+35} = 0.85$$

$$H_{o.\max} = 1.28\times 10^{-3} t_o(\gamma_w - \gamma_o)\left(\frac{d_m^2}{\mu_o}\right)$$

$$= 1.28\times 10^{-3}(10)(1.07-0.85)\left(\frac{500^2}{10}\right) = 70.4$$

$$D_{\max} = \frac{H_{o,\max}}{H_o/D} = \frac{70.4}{0.35} = 201.14$$

Same conditions as problem 9 from chapter 2

$\therefore$ Z=0.93 , $\rho_g = 1.613$, $C_d = 1.61$

a) Horizontal separator

Gas Capacity Constraint